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RESEARCH

Diel variation of plankton in the highly impacted freshwater zone of Hooghly estuary in relation to ecological alteration

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Abstract Plankton are promising ecological monitoring tool that responds quickly to any sort of aquatic ecological alteration, of which many of them are much susceptible to ecological variations. Therefore, monitoring shifts in plankton composition can indicate changes in water quality and aid to identify potential pollution sources. In the present study, the variation in plankton dynamics in relation to ecological variables were monitored in the freshwater zone of the Hooghly estuary from May 2020 to April 2021. The study was conducted in the interval of every six hours. i.e., at 6 A.M., 12 P.M., 6 P.M., and 12 A.M. The present finding revealed the occurrence of 54 phytoplankton and 20 zooplankton taxa/species. Diel variation revealed that among different time intervals, the highest abundance of phytoplankton was recorded 28,307 cells l^{-1} at 12 P.M, while the lowest was recorded 10,632 cells l^{-1} at 6 A.M. However, the highest zooplankton abundance was observed 804 ind l^{-1} at 6 A.M., and the lowest was recorded 156 ind l^{-1} at 6 P.M. The ANOVA ($p < 0.05$) analysis indicated significant diel variation for many planktonic genera. The CCA exhibited that most of the phytoplankton were influenced by multiple water quality variables such as temperature, turbidity, calcium, pH, salinity, DO, and nutrients. However, the majority of the zooplankton were affected by turbidity, total phosphorus, sulphate, calcium and available nitrogen. Significant seasonal variation in plankton composition has also been observed. The present study will help to determine the varying diel pattern of planktons in retort to alterations in the water quality parameters and varying ecological niches.

Keywords Plankton · River Ganga · Ecological factors · Diel variation · Multivariate statistical analysis · Diversity indices

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Introduction

The productivity of the aquatic ecosystem mainly depends on the dynamics of its flora and fauna. About half of global primary productivity is contributed by phytoplankton, which constitutes the base of the aquatic food web (Hitchcock, 2022; Tian et al., 2023). Nowadays many of the researchers favoured planktons as the prime bio-monitoring assessment tool for the proper management of the aquatic ecosystem (Hu et al., 2022; Mohanty et al., 2022a, b). Phytoplankton executes photosynthesis with the help of sunlight and occupies the base position in the aquatic food chain

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as a primary producer (Chen et al., 2023). Similarly, zooplankton is considered the primary consumer of the aquatic ecosystem, which plays a vital role in the formation of the aquatic food web. It is an important serving link between the primary producer (phytoplankton) and organisms of higher trophic strata of the aquatic ecosystem (Ndah et al., 2022). It is also an important food source for aquatic organisms such as fish, crustaceans, benthic organisms etc. (Cheng et al., 2023). Several authors reported that photoperiod and light intensity play an influential role in the regulation of phytoplankton dynamics (Wu et al., 2023). Light availability and its intensity affect their photosynthetic process and play an influential role in their growth and development (Gogoi et al., 2021b; Jindal & Sharma, 2011; Sarkar et al., 2019). Apart from light, several physico-chemical parameters are also known to affect the plankton community because they are very sensitive to the fluctuating environment (Kumari et al., 2017; Paerl et al., 2010). In addition to environmental factors, anthropogenic activities, periodic discharge of industrial effluent, domestic waste, climatic factors such as rainfall pattern and temperature, etc. (Gao et al., 2022; Volkmar et al., 2011) also found to have a profound impact on the plankton community. Some of the studies related to diurnal variation of the plankton community in estuaries and rivers has been reported (Fan et al., 2023; Vidal et al., 2023; Wang et al., 2023). Diurnal variations in the physico-chemical parameters affect the assemblage, distribution pattern, density, and species composition of phytoplankton and zooplankton in all versions of aquatic ecosystems viz. coastal water (Padhan et al., 2019; Soulié et al., 2023), diurnal variations in water quality parameters in wetlands (Richardson et al., 2022), and vertical distribution of phytoplankton in Lake Onego, the second largest lake of Europe (Suarez et al., 2019).

The Hooghly River runs through the state of West Bengal covering numerous districts namely Howrah, Hooghly, Nadia, Medinipur, and North and South 24 Parganas. The river flow through several tributaries in lower stretches like Ajoy-Damodar, Rupnarayan, and Haldi (Prakash et al., 2023). Each season is very specific to the Hooghly estuary, which has quite unique characteristic feature of its own (Mitra et al., 2018). Chakraborty et al., 2021; Dutta & Choudhury, 2021 studied the variation of environmental complexity with tidal currents twice–daily in the estuarine ecosystem. Tidal changes influence the turbidity and suspended particulates (organic and inorganic matriculates) in the water body, causing a variation in the light penetration pathway (Liu et al., 2020). The changes in the light pathway in the water body might alter the richness of the aquatic organisms. Plankton composition and concentration vary due to multifarious abiotic as well as biotic factors. The most significant water variables are the water temperature (Chaipiputnakhajorn & Gunbua, 2023), nutrients (Enawgaw & Wagaw, 2023), and diurnal cycle (Alam et al., 2021; Vidal et al., 2023). The fluctuation of abundance and diversity of primary consumers (zooplankton) significantly depends upon the concentration and composition of primary producers. Therefore, assessment of the variation of phytoplankton along with zooplankton is highly essential to know the food web structure and finding bio-indicator organisms.

In the present investigation, we have made an attempt to know the month-wise variation in plankton dynamics and evaluate relationship with water quality variability in the freshwater region of Hooghly Estuary with special emphasis to diel variation of the plankton genera. Very limited research is available in the riverine stretch of the river Ganga, for which diel variation of plankton including zooplankton and phytoplankton in relation to ecological alteration has been observed and studied. Diel variation is precisely important to study the dynamics of a riverine environment taking place to sustain the aquatic life. The present study will become the benchmark for the researchers and policymakers for the proper management of aquatic environment, especially in the large water bodies like rivers and wetlands.

Material and method

Study area

The study was carried out by taking riverine sub-surface water samples (30 cm) from the Hooghly-Maltah riverine ecosystem, Barrackpore (78° 44′ 15.72576″ E, 31° 2′ 17.90484″ N) of West Bengal, India. It is an estuary of the river Ganga that flows into the Bay of Bengal therefore; the region is under tidal influence. It endeavours diversified aquatic flora and fauna. Industrial waste, household sewage disposal, boating, bathing, religious ceremonies, and the occasional immersion of idols have all been known to contaminate this region, and it is also vulnerable to cyclone interventions because of its proximity to the Bay of Bengal. There are over twenty ferry ghats operated from upstream to downstream, the study site is one among them continuously operated for as transport. The samples were collected monthly from May 2020 to April 2021 with a sampling interval of 6 h i.e., at 6 A.M., 12 P.M., 6 P.M., and 12 A.M. The geographical location of the station was recorded using handheld GPS (Garmin, USA). The flow chart of the sampling methodology has been provided in Fig. 1. The map of study sites was created using ArcGIS and presented in Fig. 2.

Analysis of physico-chemical parameter

The water samples were collected for the analysis of water quality parameters using an autoclaved and acid-washed HDPE bottle (1 L) (ABDOS ®) and glassware (Borosil®). The parameters such as pH, specific conductivity, water temperature, etc. were measured on site using the YSI multi-parameter probe (Model:—YSI-Pro DSS, USA). The samples were brought to the laboratory for analysis of nutrients and other essential parameters such as total and available nitrogen, total and available phosphorus, and silicate. The transparency of water was measured using the Secchi disk. The dissolved oxygen was measured in the field following the Winkler method (APHA, 2017). In this process the sample was added with 1 ml of manganous sulphate followed by 1 ml of alkaline iodide solution to fix the dissolved oxygen. After that the samples was added with 1 ml of concentrated sulphuric acid. Lastly 100 ml of sample was taken into conical flask then 4–5 drops of starch were added to it, and titrated with N/80 standard thiosulphate solution up till the endpoint blue to colorless was detected.

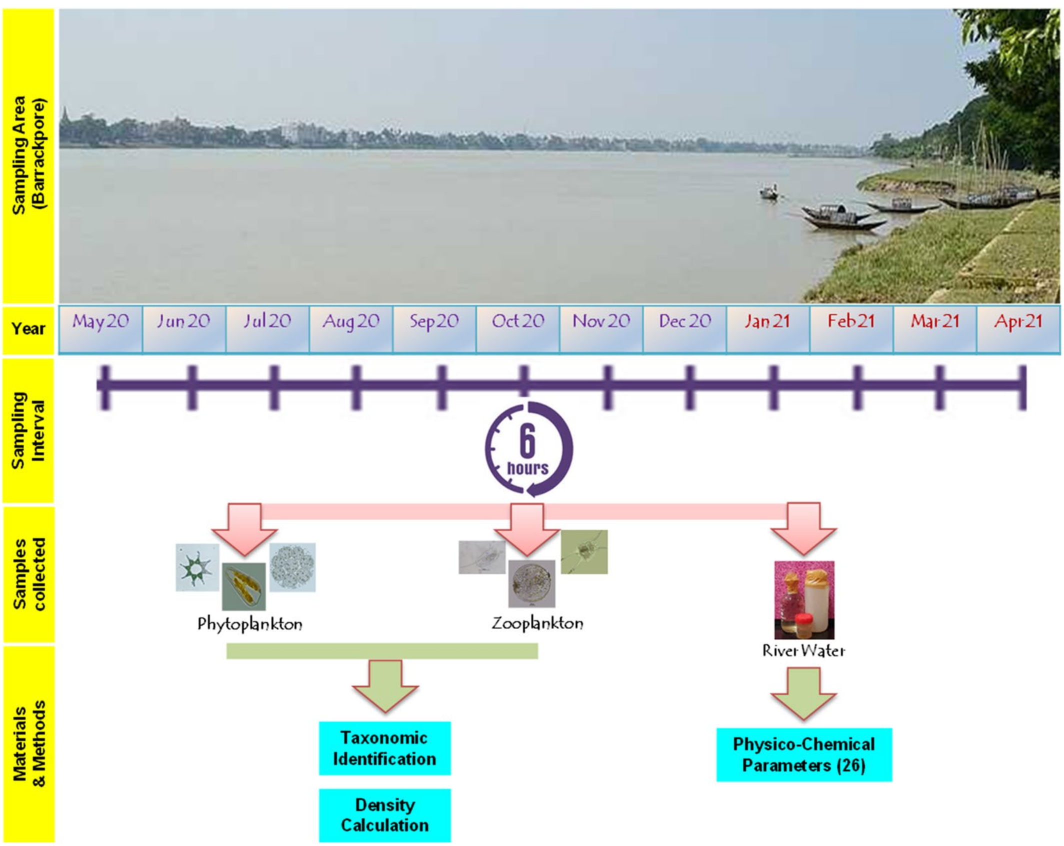

Fig. 1 Flow chart of methodology

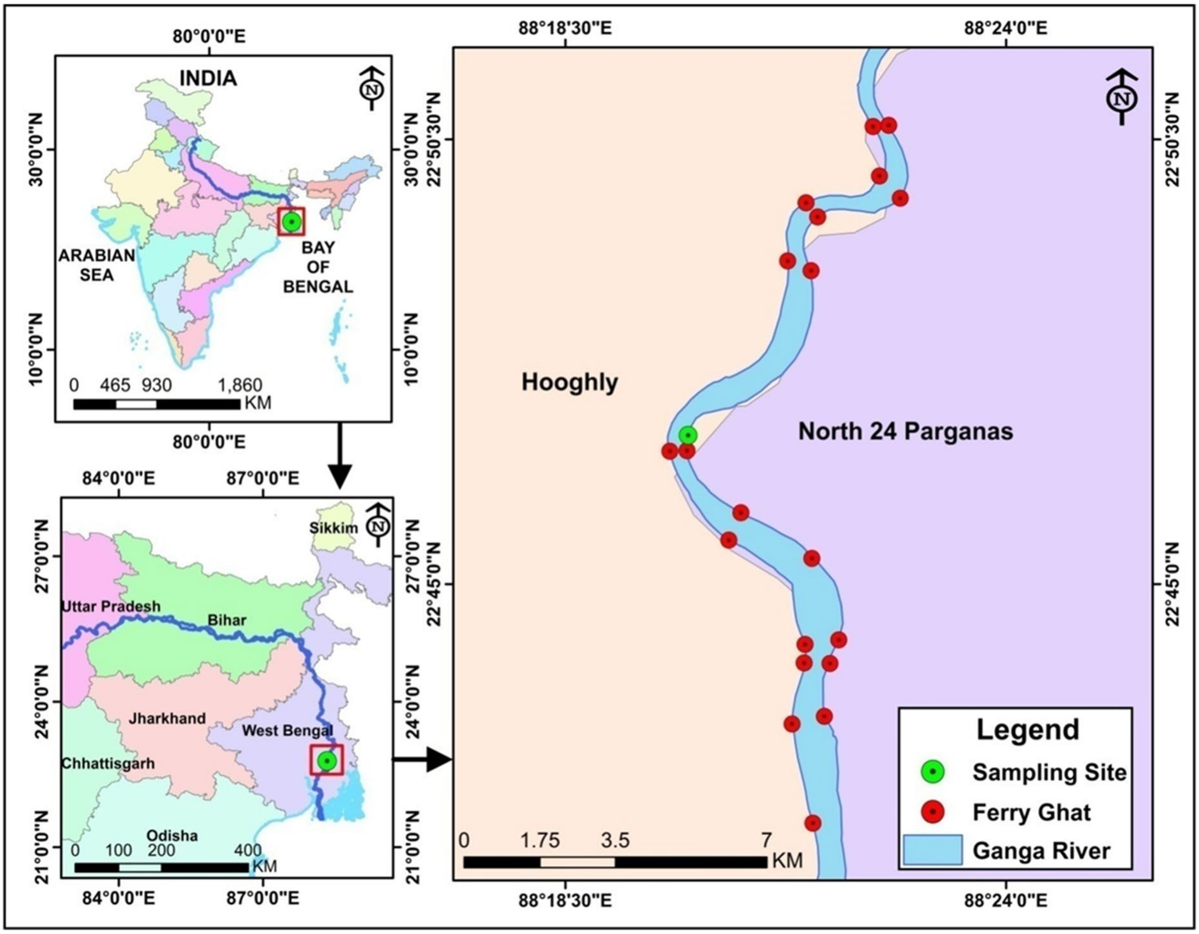

Fig. 2 Study area map of Hooghly-Matlah Estuary

The parameters such as total hardness, total alkalinity, and free Co_2 were also estimated onboard by the titrimetric method following APHA, 2017.

Total hardness The sample was titrated with the aid of ethylene diamine tetra acetic acid (EDTA) disodium salt (0.01 M), using the Eriochrome Black-T as indicator. Ammonia buffer was used to adjust the sample's pH to 10 ± 0.1. A 50 ml water sample was obtained for the analysis, and 1 ml of ammonium buffer was added. Additionally, the material was titrated up till the endpoint (blue to magenta) was detected.

Total alkalinity Using the titrimetric approach and the indicators bromocresol green-methyl red and phenolphthalein, alkalinity was determined. A 100 ml sample was taken for the hydroxide and carbonate alkalinity, and Phenolphthalein indicator was used. If pink colour developed, the sample was titrated using N/50 sulphuric acid until the colourless point was detected. The BCG mixed indicator was used to measure the the bicarbonate alkalinity, if the sample-coloured blue-green when employing the indicator, it was titrated with the aid of N/50 sulfuric acid until the red coloration endpoint was noted.

Free Co_2 Using the titrimetric approach and a Phenolphthalein indicator with an endpoint pH of 8.3, free carbon dioxide was determined. 50 ml of the sample was obtained for analysis, and it was titrated using the Phenolphthalein indicator and N/44 NaOH solution.

Chlorophyll Sub-surface water sample were collected for chlorophyll analysis in the amber-coloured bottle. The filtration for the chlorophyll sample was done in the field using a vacuum pump (Milipore®,Model: -Vaccum PR, PUMP 4 BAR) with the help of Whatman® nitrocellulose filter paper (0.45 μm). The filtrate was wrapped in aluminium foil and transported to the laboratory in refrigerated condition. In the laboratory, the chlorophyll pigments were extracted with the help of a tissue homogenizer and centrifuge (Tarson® Spinwin, MC05-R). Finally, the chlorophyll samples were analysed using the acetone-extraction method.

Nutrient analysis

Nutrient parameters: total nitrogen, available nitrogen, silicate and sulphate were analysed following standard methodology (APHA, 2017). Before each sampling, the standard curves were drawn using standard reagents for each of the parameters. The essential instruments such as the spectrophotometer, water bath etc. were calibrated before each use. During each of the analyses, the sample blank was also taken into consideration.

The total nitrogen analysis was done following the Kjeldahl method. For the analysis, the sample was digested using sodium hydroxide and devarda's alloy, and the digested sample was collected from the distillation unit. The spectrophotometric readings were taken with the help of Nessler's reagent which is used as the indicator.

The available nitrogen was analysed using the phenol disulphonic acid method. In which the sample was dried, and later phenoldisulphonic acid and sodium hydroxide were used consecutively. Then the readings were taken with the help of a spectrophotometer after the adding Nessler's reagent as indicator.

For the analysis of available phosphorus all the glassware used were pre-washed with phosphorus-free detergent. 25 ml of water sample was filtered (Whatman 1). After that 4 ml colour developing reagent (blue) was added. Then the readings were taken with the help of a spectrophotometer.

For the analysis of total phosphorus, all the glassware used were pre-washed with phosphorus-free detergent. For total phosphorus the sample was reduced with the help of a hot plate, then perchloric acid was used, then neutralised with the help of sodium hydroxide, in which phenolphthalein was used as the indicator. Finally, the processed sample was analysed using the ascorbic acid method.

The silicate analysis was done by following the ammonium molybdate method, in which ammonium molybdate, oxalic acid and hydrochloric acid were used for the analysis. Then the readings were taken with the help of a spectrophotometer at 410 mm.

The sulphate was analysed using the Turbidimetric method (APHA, 2017). A total 50 ml glass standard flask was taken. After that 10 ml, 20 ml, 30 ml, 40 ml of standard suphate solution was added to first, second, third, fourth to flask respectably. The fifth flask was added with 20 ml of the sample water. The sixth flak was remained blank. After that all the flask was added with 5 ml of conditioning reagent. Then the readings were taken with the help of a spectrophotometer.

Plankton collection and analysis

Plankton samples (phytoplankton and zooplankton) were collected from the sub-surface water and analysed using the method described by Gogoi et al., 2019; Parakkandi et al., 2021. Briefly, the phytoplankton samples were concentrated by filtering 100 L water through the plankton net, having a mesh size of 20 μm (mouth dia. 60 cm). The condensed samples were shifted to an HDPE plankton plastic tube (Tarsons®) and preserved by using a combination of 4% neutral buffered formalin solution and 2 ml Lugol's iodine solution. Samples were analyzed by employing a trinocular inverted light microscope (40 × and 60 × magnification; model:- A1 AXIO, Scope A1 make:- Zeiss), and identified using several standard published literature Desikachary, 1959; Cox & Cox, 1996; Bellinger & Sigee, 2015). For taxonomic analysis, 25–30 sample patches were used. Algaebase (www.algaebase.org) was followed for the validation of updated names and taxonomic positions (Guiry & Guiry, 2020). Quantitative analysis was carried out and expressed as cells per litre (cells l^{-1}).

Zooplankton samples were accumulated by filtering 100 L sub-surface water through a 40 μm mesh size net (mouth dia. 60 cm). The collected samples were shifted to a HDPE plastic plankton collection tube (Tarsons®), and preserved with a 4% buffered formalin solution. The Sedgwick – Rafter counting chamber (S – R cell) as well as Petri dish was applied for making the inventory of zooplankton under a trinocular compound light microscope (20 × and 40 × magnification, model:—A1 AXIO, Scope A1make:—Zeiss). The classification of zooplankton was done by referring to standard taxonomic keys (Al-Yamani et al., 2011; Kasturirangan, 1963; Shiel, 1995; Ward et al., 1918). The zooplankton abundance was depicted as the number of individuals per litre (Basu et al., 2021).

Statistical data analysis

The one-way analysis of variance (ANOVA) followed by the Post hoc (Duncan's) test was performed to recognize the significant variations among the plankton groups at different times. The test was also used to evaluate the significant differences in physico-chemical parameters during different time intervals using SPSS v.21 (IBM Corp. 2013). We used Past 4.02 software to assess the species diversity indices like Shannon, Simpson, and Margalef index. Canonical Correspondence Analysis (CCA)—was used to distinguish the plankton species influenced by environmental constraints. Bray – Curtis similarity is based on hierarchical clusters of different periods demonstrated using a dendrogram. Both CCA and Bray – Curtis hierarchical clusters were analyzed using the Past 4.02 software.

Results

Physicochemical parameters

The mean water temperature (°C) during the study period was found maximum (28.49 ± 2.43°**C**) at 12 P.M. and minimum temperature (25.96 ± 2.34°**C**) was observed at 12 A.M. Throughout the study period, the mean pH of the river indicated that the quality of the river water remained alkaline. Among the nutrients, silicate was recorded maximum (14.84 ± 4.30 ppm) at 12 P.M. Total nitrogen and available nitrogen peaked (0.6 2 ± 0.01 ppm and 0.03 ± 0.003 ppm respectively) at 12 A.M., while the total phosphorus and available phosphorus peaked (0.40 ± 0.23 ppm and 0.08 ± 0.01 ppm respectively) at 6 A.M. The highest mean salinity (0.14 ± 0.05 ppt) was found at 6 A.M. and 12 A.M. and lowest (0.12 ± 0.05 ppt) during 12 P.M. The average value of the water quality variables during different time intervals has been summarized in Table 1. The ANOVA was performed followed by the Duncan post-hoc test ($P < 0.05$) showed no significant variation in water quality parameters during any of the time intervals.

Karl Pearson correlation was performed among the water quality parameters, it was observed that water temperature had a significant positive correlation with turbidity ($r = 0.345$, $p < 0.05$), and free CO_2 ($r = 0.399$, $p < 0.01$), while a significantly negative correlation was observed with sp. conductivity ($r = -0.664$, $p < 0.01$), dissolved oxygen ($r = -0.795$ $p < 0.01$), total alkalinity ($r = -0.675$, $p < 0.01$) and total hardness ($r = 0.794$, $p < 0.01$). Turbidity showed a substantial negative correlation with dissolved oxygen ($r = -0.455$, $p < 0.01$). Sp. conductivity was positively correlated with dissolved oxygen ($r = 0.691$, $p < 0.01$), pH ($r = 0.516$, $p < 0.01$), total alkalinity ($r = 0.836$, $p < 0.01$), and total hardness ($r = 0.712$, $p < 0.01$) while negatively correlated with free CO_2 ($r = -0.441$, $p < 0.01$). pH showed a significant positive correlation with total alkalinity ($r = 0.516$, $p < 0.01$), and total hardness ($r = 0.522$, $p < 0.01$) whereas, it showed a significant negative correlation with free CO_2 ($r = -0.317$, $p < 0.01$). Dissolved oxygen showed a significant positive relation with total alkalinity ($r = 0.633$, $p < 0.01$) and total hardness ($r = 0.735$, $p < 0.01$) whereas, a significantly negative correlation was observed with free CO_2 ($r = -0.418$, $p < 0.01$) total alkalinity showed a significant negative correlation with free CO_2 ($r = -0.562$, $p < 0.01$) (Fig. 11).

Plankton assemblage

Plankton samples, collected monthly diurnal during the year, were analysed and their assemblage pattern has been illustrated in Fig. 3. Among the different groups, Bacillariophyceae was found maximum in the month of April 2021, while the minimum assemblage of Bacillariophyceae was observed in month of October 2020. The group, Dinophyceae was dominated in December 2020 and February 2021, while the least dominance was observed in all the other months. The group, Ulvophyceae was only observed in the months of May 2020 and November 2020. The group Chlorophyceae was found to be dominant in the month of May and December 2020 and the least observation was recorded in the months of October 2020 and

Table 1 Physico-chemical parameters of River Ganga

Physico-chemical Parameters	6 A.M	12 P.M	6 P.M	12 P.M
Water Temperature (^{0}C)	26.11 ± 1.29	28.49 ± 2.44	27.20 ± 2.32	25.96 ± 2.35
Turbidity (NTU)	59.34 ± 20.14	82.34 ± 10.49	69.67 ± 11.97	88.45 ± 8.81
Conductivity (mS/cm)	0.35 ± 0.02	0.34 ± 0.03	0.34 ± 0.03	0.35 ± 0.03
pH	7.79 ± 0.10	7.91 ± 0.66	7.98 ± 0.62	8.07 ± 0.65
DO (ppm)	6.44 ± 0.35	6.92 ± 0.70	6.51 ± 0.59	6.40 ± 0.58
Total alkalinity (ppm)	130..06 ± 7.10	132.02 ± 12.13	133.79 ± 12.75	126.96 ± 11.76
Free co_2	2.46 ± 0.60	2.13 ± 0.68	2.99 ± 1.07	4.69 ± 2.12
Salinity	0.14 ± 0.05	0.12 ± 0.05	0.13 ± 0.05	0.14 ± 0.06
Total Hardness (ppm)	129.58 ± 6.66	130.75 ± 12.45	128.96 ± 12.05	124.79 ± 12.12
Calcium Hardness (ppm)	29.34 ± 0.98	29.20 ± 2.48	28.51 ± 2.43	28.46 ± 2.24
Magnesium Hardness (ppm)	19.09 ± 4.67	18.24 ± 3.56	17.85 ± 3.43	17.65 ± 4.78
Available phosphate (ppm)	0.08 ± 0.01	0.07 ± 0.01	0.08 ± 0.01	0.08 ± 0.01
Total phosphate (ppm)	0.40 ± 0.23	0.21 ± 0.02	0.43 ± 0.02	0.22 ± 0.03
Available nitrate (ppm)	0.02 ± 0.01	0.02 ± 0.01	0.02 ± 0.01	0.03 ± 0.01
Total nitrate (ppm)	0.05 ± 0.01	0.06 ± 0.01	0.06 ± 0.01	0.06 ± 0.01
Silicate (ppm)	10.68 ± 1.14	14.84 ± 4.30	9.94 ± 0.99	10.35 ± 1.12
Sulphate (ppm)	0.17 ± 0.11	0.12 ± 0.01	0.12 ± 0.01	0.11 ± 0.01
Total Solid (ppm)	0.25 ± 0.04	0.22 ± 0.02	0.20 ± 0.02	0.21 ± 0.03
Total Dissolved Solid (ppm)	0.20 ± 0.03	0.17 ± 0.02	0.15 ± 0.02	0.21 ± 0.03
Total Suspended Solid (ppm)	0.07 ± 0.03	0.05 ± 0.01	0.010 ± 0.01	0.05 ± 0.88
BOD	1.21 ± 0.11	1.57 ± 0.22	1.20 ± 0.18	1.32 ± 0.25
CHLA	3.91 ± 0.91	3.83 ± 0.97	5.56 ± 1.48	4.79 ± 1.08
CHLB	1.75 ± 0.58	1.19 ± 0.20	2.10 ± 0.62	2.21 ± 0.68
CHLC	2.30 ± 0.88	1.40 ± 0.26	2.45 ± 0.75	2.61 ± 0.78
T CHL	7.96 ± 1.99	5.96 ± 1.25	10.12 ± 2.53	9.61 ± 2.46
COD	48.86 ± 8.74	40.61 ± 7.48	49.28 ± 8.92	42.74 ± 8.89

February 2021. The group Trebouxiophyceae was observed maximum in the months of December 2020 and February 2021. The Zygnematophyceae group was observed maximum in the months of January and April 2021. The group Euglenophyceae was found to be dominant during June and July 2020, however, the least abundance was observed in the months of October 2020, and January-March 2021. Cyanophyceae was observed maximum in the months of June and September 2020, and February 2021. The minimum abundance of the group Cyanophyceae was observed in the months of October 2020 and March 2021. Among the zooplankton, the group Arthropoda and Rotifera dominated in the month of April 2021, while the least dominance was observed in the month of October 2020. Ciliophora was observed maximum during May, June and December 2020. The group Amoebazoa was observed maximum in the months of June, September and December 2020.

Phytoplankton diel variation

A total of 54 genera of phytoplankton belonging to11 algal groups were recorded during the study. The recorded algal groups were Bacillariophyceae (14), Coscinodiscophyceae (3), Chlorophyceae (8), Trebouxiophyceae (4), Cyanophyceae (13), Zygnematophyceae (5), and Euglenophyceae (3). The least species diversity was recorded for Mediophyceae,Synurophyceae, Ulvophyceae, and Dinophyceae (one genus from each group). Out of eleven algal groups, Coscinodiscophyceae accounted for the maximum in terms of quantitative abundance (59%) followed by Cyanophyceae (29%), and Bacillariophyceae (3%). Out of 18 identified genera of

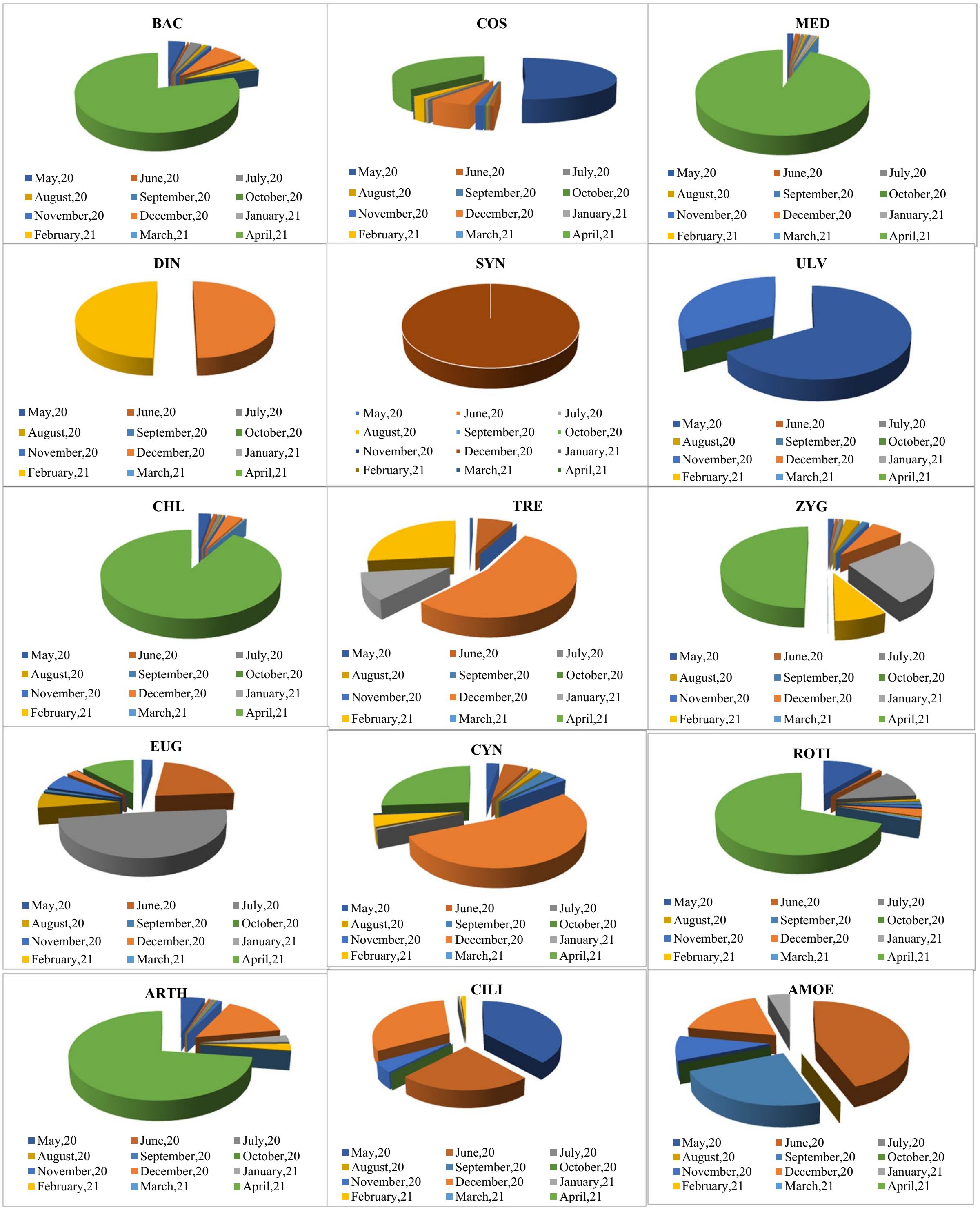

Fig. 3 Percentage contribution of plankton groups during different month of 2020–2021 year. Bac—Bacillariophyceae, Cos—Coscinodiscophyceae, Med—Mediophyceae, Din-Dinophyceae, Syn—Synurophyceae, Ulv -Ulvophyceae, Chl—Chlorophyceae, Tre -Trebouxiophyceae, Zyg—Zygnematophyceae, Eug-Euglenophyceae, Cya – Cyanophyceae, Rot-Rotifera, Arth- Arthropoda, Cili- Ciliophora, Amoe– Amoebazoa

diatoms, the Pennales showed an overall dominance among others. The centric diatoms such as *Coscinodiscus* sp. were recorded as the most abundant between 6 A.M. and 6P.M. under the group, Cyanophyceae; *Chroococcus* sp., *Microcystis* sp., *Anabaena* sp., *Nostoc* sp., *Phormidium* sp., etc. were recorded as abundant species. Chlorophyceae was accounted for the genera *Coelastrum* sp., *Scenedesmus* sp., *Volvox* sp., *Eudorina* sp., *Pediastrum* sp., *Westella* sp., and *Monoraphidium* sp. In the group Zygnematophyceae *Mougeotia* sp., *Cosmarium* sp., *Closterium* sp., *Staurastrum* sp, and *Spirogyra* sp. Were recorded during study.

In the study, the maximum mean phytoplankton abundance (28307cellsl^{-1}) was observed at 12 P.M., followed by (14,971 cells l^{-1}) at 12 A.M., (10,632 cells l^{-1}) at 6 A.M., and (10,490 cells l^{-1}) at 6 P.M. The percentage contribution of the phytoplankton group throughout the sampling year was depicted in Fig. 4. The Bacillariophyceae, Mediophyceae, Dinophyceae, Euglenophyceae and Cyanophyceae was recorded at 12 P.M. The Chlorophyceae and Trebouxiophyceae abundance was observed maximum at 6 A.M. The abundance of Ulvophyceae and Zygnematophyceae were found maximum at 6 P. M. Coscinodiscophyceae had highest density at 6 A.M.

The ANOVA was performed followed by post hoc test showed significant variation ($p \leq 0.05$), in many phytoplankton organisms like *Meridion* sp., *Diatoma* sp., *Pseudonitzschia* sp., *Gyrosigma* sp., *Diploneis* sp., *Cymbella* sp., *Gomphonema* sp., *Acanthoceros* sp., *Ceratium* sp., *Mallomonas* sp., *Ulothrix* sp., *Volvox* sp., *Eudorina* sp., *Westella* sp., *Treubaria* sp., *Crucigenia* sp., *Cosmarium* sp., *Euglena* sp., *Phacus* sp., *Trachelomonas* sp., *Gomphosphaeria* sp., *Aphanothece* sp., *Aphanizomenon* sp., *Anabaena* sp., *Nostoc* sp., *Lyngbya* sp., *Gloeocapsa* sp., *Spirulina* sp. during different time periods for the diel variation. However, in some species like *Nitzschia* sp., *Navicula* sp., *Fragilaria* sp., *Synedra* sp., *Surirella* sp., *Bacillaria* sp., *Coscinodiscus* sp., *Aulacoseira* sp., *Cyclotella* sp., *Coelastrum* sp., *Scenedesmus* sp., *Pediastrum* sp., *Dictyosphaerium* sp., *Actinastrum* sp., *Closterium* sp., *Staurastrum* sp., *Spirogyra* sp., *Mougeotia* sp., *Chroococcus* sp., *Oscillatoria* sp., *Phormidium* sp. no significant variations have been observed for the diel study.

Dominant species of phytoplankton

Aulacoseira sp. (Coscinodiscophyceae) was found to be the single dominant genera recorded having a maximum contribution of 38–88% of the total phytoplankton population. It contributes about 86–98% of the total diatom. In the group Mediophyceae: *Cyclotella* sp. was found to be the dominating species. *Eudorina* sp. and *Pediastrum* sp. were found to be dominant in the group Chlorophyceae, contributing 9–96% of the total Chlorophyceae population. These species were dominant at 6 A.M. and 6 P.M. The *Ceratium* sp. was found to be the dominating species in the group Dinophyceae, and it was found only at two of the time periods i.e., at 6 A.M. and 12 P.M. *Acanthoceros* sp. of group Coscinodiscophyceae and *Treubaria* sp. of Chlorophyceae were only observed at May 2020 at 12 A.M. Under the group, Cyanophyceae *Microsystis* sp. and *Anabaena* sp. were observed maximum at 12 P.M., The *Staurastrum* sp. was found to be the dominating genera in the group Zygnematophyceae.

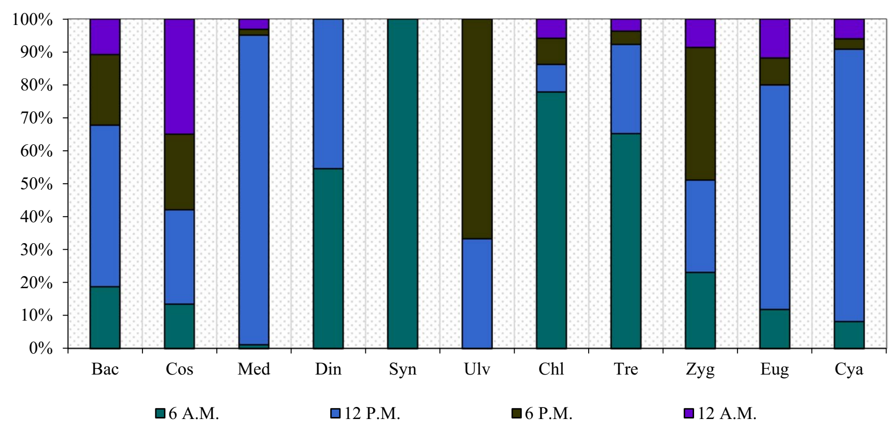

Fig. 4 Phytoplankton group percentage contribution. Bac—Bacillariophyceae, Cos—Coscinodiscophyceae, Med—Mediophyceae, Din-Dinophyceae,Syn—Synurophyceae, Ulv -Ulvophyceae, Chl—Chlorophyceae, Tre -Trebouxiophyceae, Zyg—Zygnematophyceae, Eug-Euglenophyceae, Cya–Cyanophyceae

Zooplankton diel variation

A total of 20 genera of zooplankton belonging to 4 phyla (Rotifera, Arthropoda, Ciliophora, and Amoebozoa) were recorded during the entire study period. Among zooplankton, Rotifera accounted for 8 genera, followed by Ciliophora (5 genera), Copepoda (3 genera), Cladocera (2 genera), and Amoebozoa (2 genera). Copepoda accounted for the maximum abundance (39%) followed by Rotifera (32%), Ciliophora (20%), Cladocera (5%), and Amoebozoa (4%). Among zooplankton, the genus *Keratella* sp. (Rotifera) alone contributed 11–54% of the total zooplankton population. *Brachionus* sp., *Keratella* sp., *Polyarthra* sp., *Filinia* sp., *Testudinella* sp., *Asplanchna* sp., and *Monostyla bulla* were observed from the group Rotifera. *Tintinids*, *Vorticella* sp., *Podophrya* sp., *Stenor* sp., etc. belong to the Ciliophora group. Under the group Arthropoda, two sub-groups were present, namely Copepoda, and Cladosera. Under the group, Arthropoda *Cyclopoid* sp., *Diaptomus* sp., *nauplii*., *Daphinia* sp., and *Bosmina* sp. were recorded. Rotifera, Copepoda and Amoebozoa had scored the maximum value at 6 A.M. The density of Cladocera was found high at 6 P.M. Ciliophora group was found high at 12 A.M.

The zooplankton showed the maximum abundance (804 ind. l^{-1}) at 6 A.M., followed by (332 ind. l^{-1}) at 12 P.M., (184 ind. l^{-1}) at 12 A.M., and (156 ind. l^{-1}) at 6 P.M. The percentage contribution of the zooplankton group has been provided in Fig. 5. One-way ANOVA followed by Duncan post-hoc test showed significant variation ($p \leq 0.05$) in many of the zooplankton species like *Lecane* sp., *Asplanchna* sp., *Polyarthra* sp., *Testudinella* sp., *Daphnia* sp., *Bosmina* sp., *Podophrya* sp., *Stentor* sp., *Trinema* sp., *Difflugia* sp., *Centropyxis* sp. during the diel variation. Some species like *Brachionus* sp., *Keratella* sp., *Filinia* sp., *Trichocerca* sp., Cyclopoid copepod, *Diaptomus* sp., *Tintinids* were found to be insignificant during the diel study.

The variation of recorded plankton groups in different time intervals is given in Fig. 6. Photographs of some recorded plankton during the entire study period have been tabulated in Fig. 7.

Dominant species of zooplankton

Keratella sp. was most dominant species (abundance) in the group Rotifera and was observed maximum at 6 A.M. *Diaptomus* sp. was found to be the dominating genera among the Arthropoda group at 6 A.M. Similarly, *Tintinids* sp. was found to the maximum under the group Ciliophora at 6 A.M.

Seasonal variation of plankton

Total plankton density and diversity varied seasonally as well as diurnally. The diel variation of plankton abundance in four different seasons was represented in Fig. 8. During pre-monsoon, the density of phytoplankton was observed at maximum (66,067 cells l^{-1}) at 12 P.M. while the minimum density (25,519 cells l^{-1}) at 6 A.M. The density of zooplankton during pre-monsoon was found highest (2962 ind l^{-1}) at 6 A.M. and the lowest density (196 ind l^{-1}) at 6 P.M. During Monsoon season, both phytoplankton and zooplankton abundance was found to be higher (2334 cellsl^{-1} & 211 indl^{-1} respectively) at 12 P.M., while relatively lower density (1460 cells l^{-1}) was noticed at 6 P.M. and (25 indl^{-1}) at 12 A.M. During post-monsoon season, both phytoplankton and zooplankton abundance was found maximum

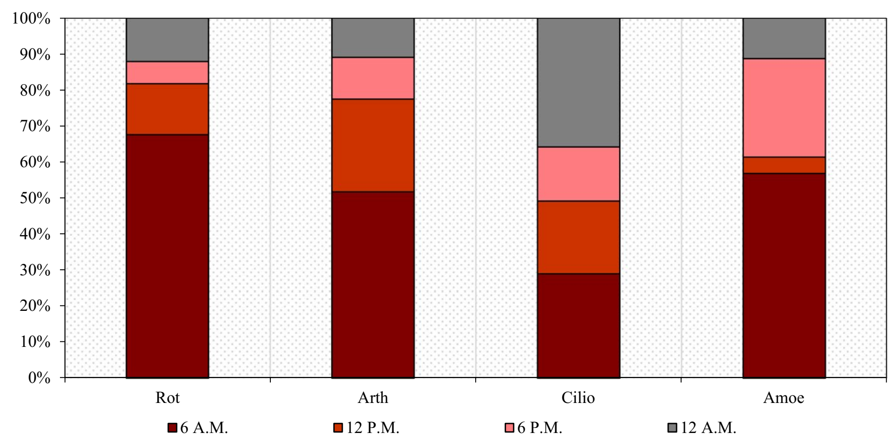

Fig. 5 Zooplankton group percentage contribution. Rot-Rotifera, Arth-Arthropoda, Cilio- Ciliophora, Amoe–Amoebazoa

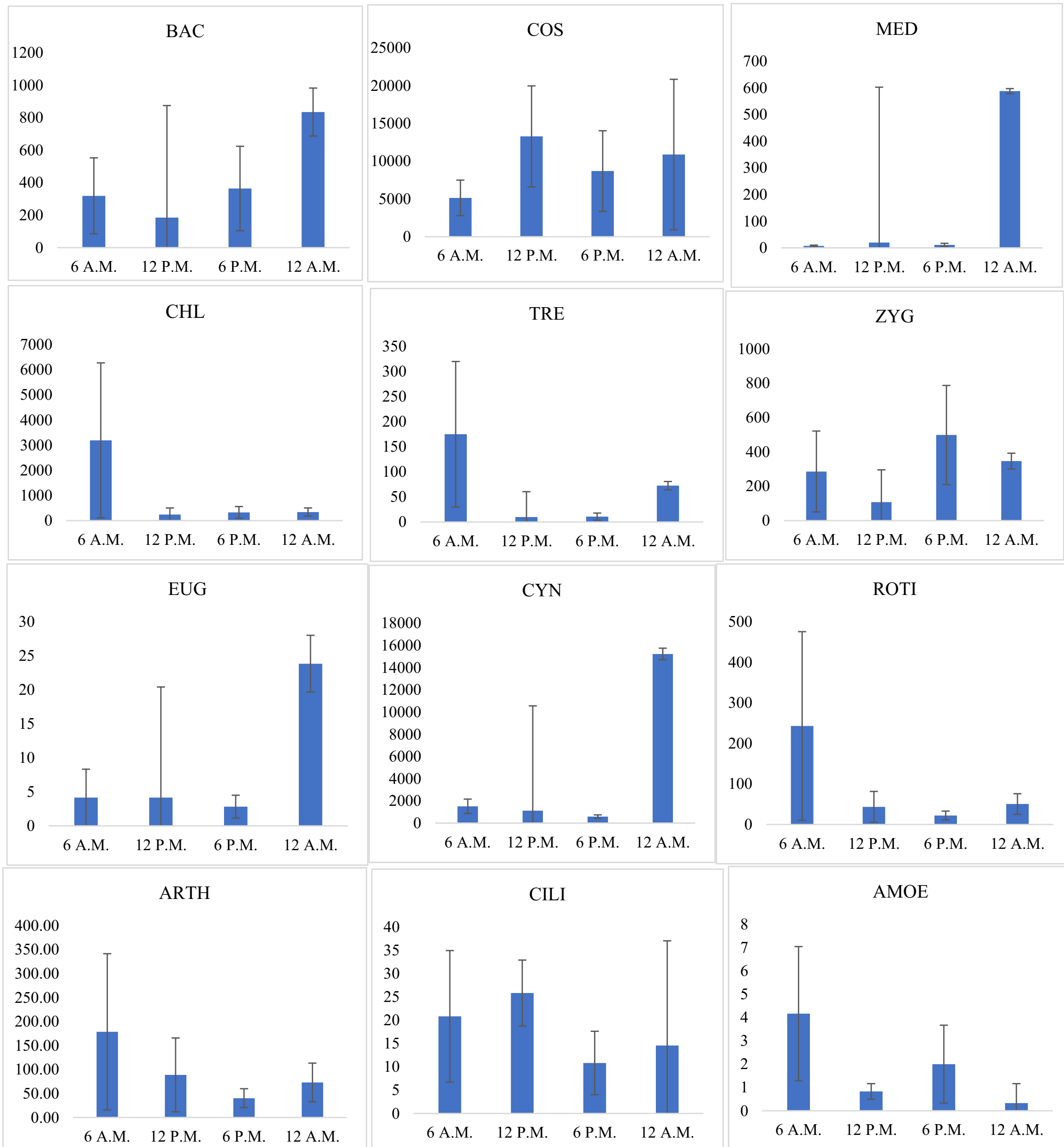

Fig. 6 Plankton group variation at different time interval. Bac—Bacillariophyceae, Cos—Coscinodiscophyceae, Med—Mediophyceae, Chl—Chlorophyceae, Tre -Trebouxiophyceae, Zyg—Zygnematophyceae, Eug-Euglenophyceae, Cya – Cyanophyceae, Rot-Rotifera, Arth- Arthropoda, Cili- Ciliophora, Amoe– Amoebazoa

(2645 cellsl^{-1}& 52 indl^{-1} respectively) at 6 A.M. while the minimum (676 cellsl^{-1}) at 12 A.M. and (8 indl^{-1}) at 12 P.M. During winter, the density of phytoplankton was recorded as high (3057 cellsl^{-1}) at 12 P.M. and low at 12 A.M. The zooplankton abundance was found maximum (357 indl^{-1}) at 6 P.M. and minimum (127 indl^{-1}) at 12 P.M. In groups like Bacillariophyceae, Coscinodiscophyceae, Trebouxiophyceae, Euglenophyceae and Ulvophyceae seasonal variations were found to be significant.

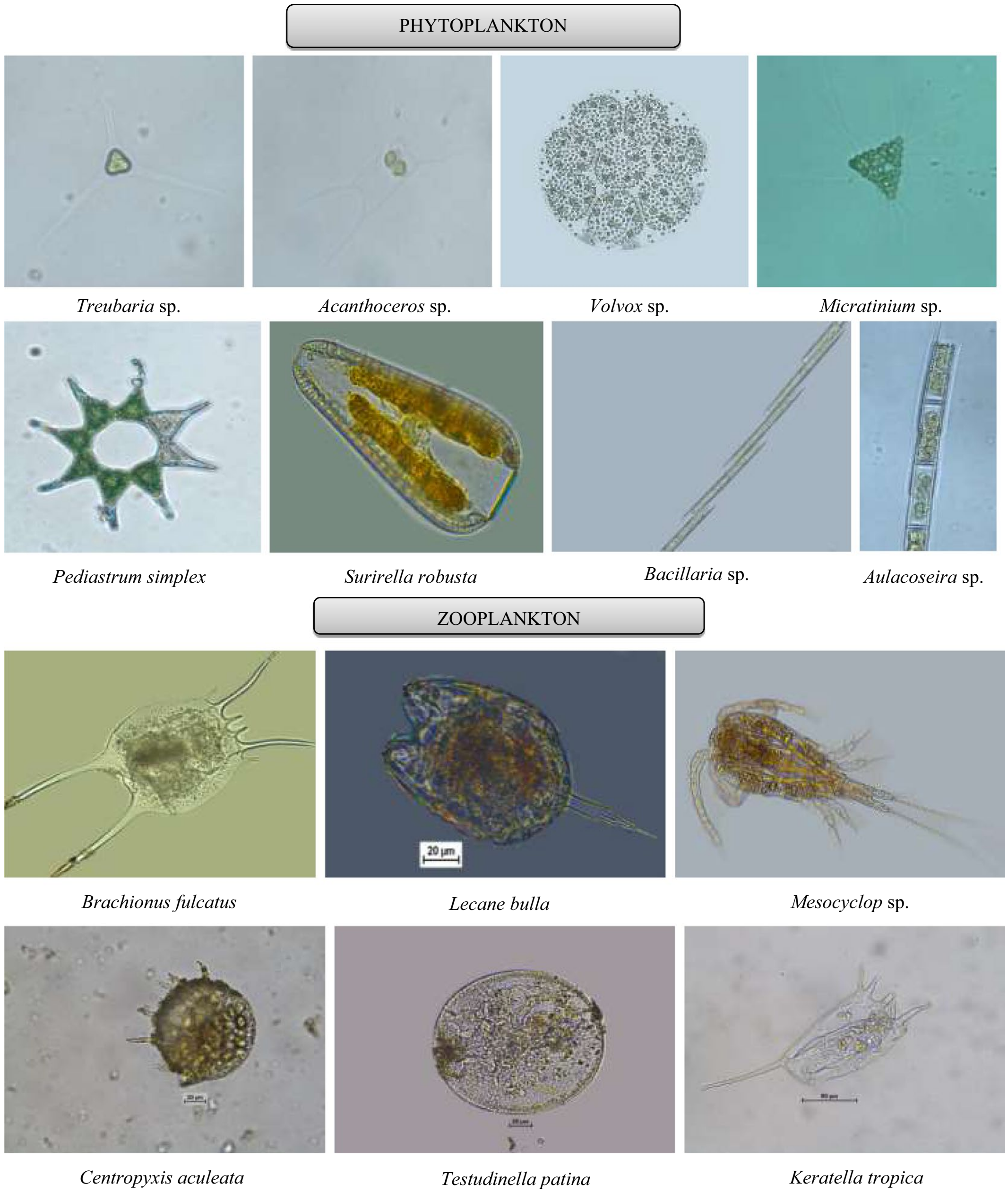

Fig. 7 Recorded planktonspecies during diel analysis

Species richness and diversity

The temporal distribution of phytoplankton richness was recorded differently in different time intervals 6 A.M. (total no. of genera = 39) > 12 P.M. and 6 P.M. (total no. of genera = 37) > 12 A.M. (total no. of genera = 34). Similarly, zooplankton richness was recorded as 6 P.M. (total no. of genera = 16) > 6A.M., 12 P.M. and 12 A.M. (total no. of genera = 14). The diversity indices like Shanon (1.71), Margalef (4.10) and Evenness (0.14) index of phytoplankton were found highest at 6A.M. The lowest index values were recorded at 12 A.M. i.e., Shanon (0.56), Margalef (3.43) and Evenness (0.05) respectively. The recorded dominance index value was inversely proportional to the Simpson index and was recorded highest at 12 A.M. (0.22) whereas; the lowest was documented at

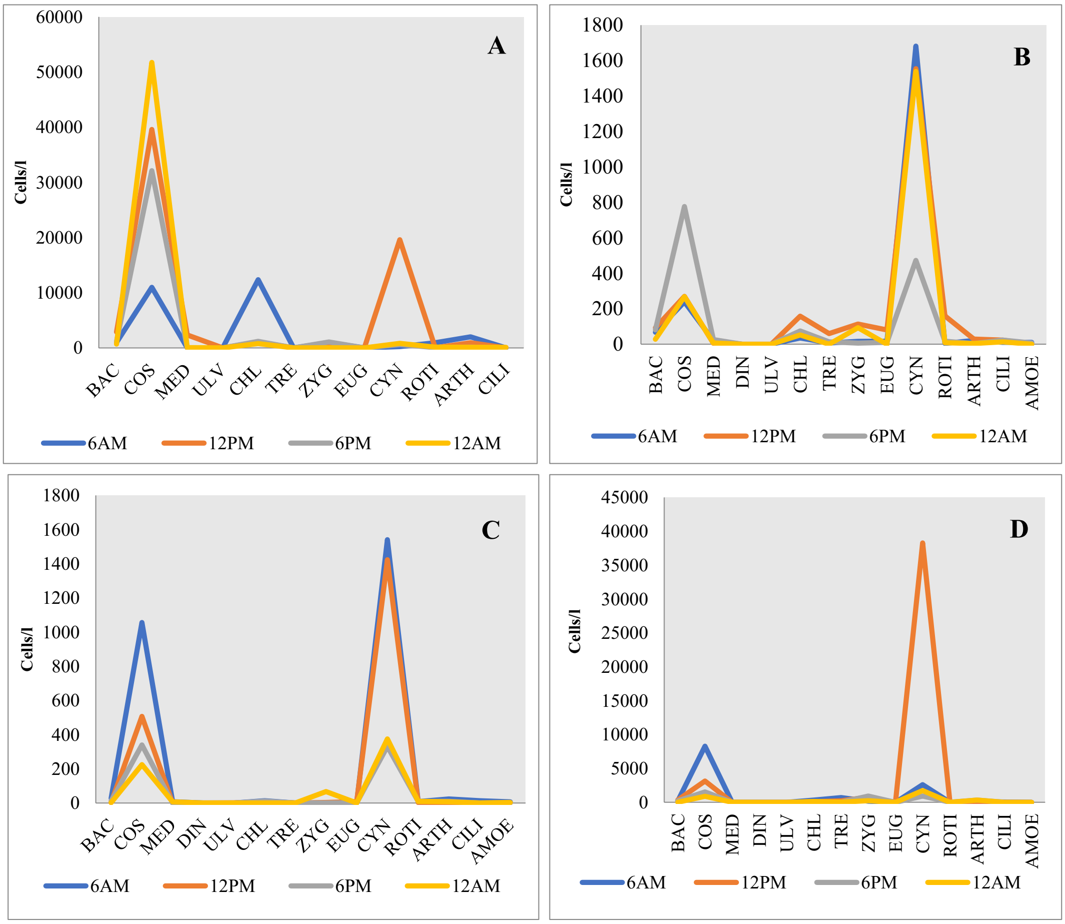

Fig. 8 Seasonal diel variation of the plankton groups [**A** -Pre-monsoon, **B** -Monsoon, **C**- Post-monsoon, **D** – Winter]

6A.M. and 12 P.M. (0.72). It can be concluded that overall phytoplankton diversity differed among four time periods. Similarly, indices of zooplankton such as Shanon (1.98), Margalef (2.51) and Evenness (0.52) index were found highest at 12 P.M. Diversity indices of both phytoplankton- and zooplankton were represented in Fig. 9.

On the occasion of diel variation, the utmost number of taxa of plankton was noticed during 6A.M. and 6 P.M. (53 genera each) followed by 12 P.M. (51 genera) and 12 A.M. (48 genera). The maximum value of the Simpson index was found at 6 A.M. (0.75) and the minimum was (0.23) recorded at 12 A.M. Similarly, the Shannon and Evenness index was also found higher at 6 A.M. and its minimum value was observed at 12 A.M for pooled plankton abundance data.

Species similarity

The Bray Curtis cluster shows the similarity of the planktonic species composition amid the four-time period during diel variation (Fig. 10). Among the three cluster groups, the highest similarity of species composition (75%) has been found between 6 P.M. and 12 A.M. Similarly, Cluster II comprising 6 P.M., 12 A.M. and 6 A.M. has 60% species composition similarity. The last cluster group was formed between 12 P.M. and 6 A.M. having 52% species composition similarity. The last cluster group has been found to be with the lowest species similarity.

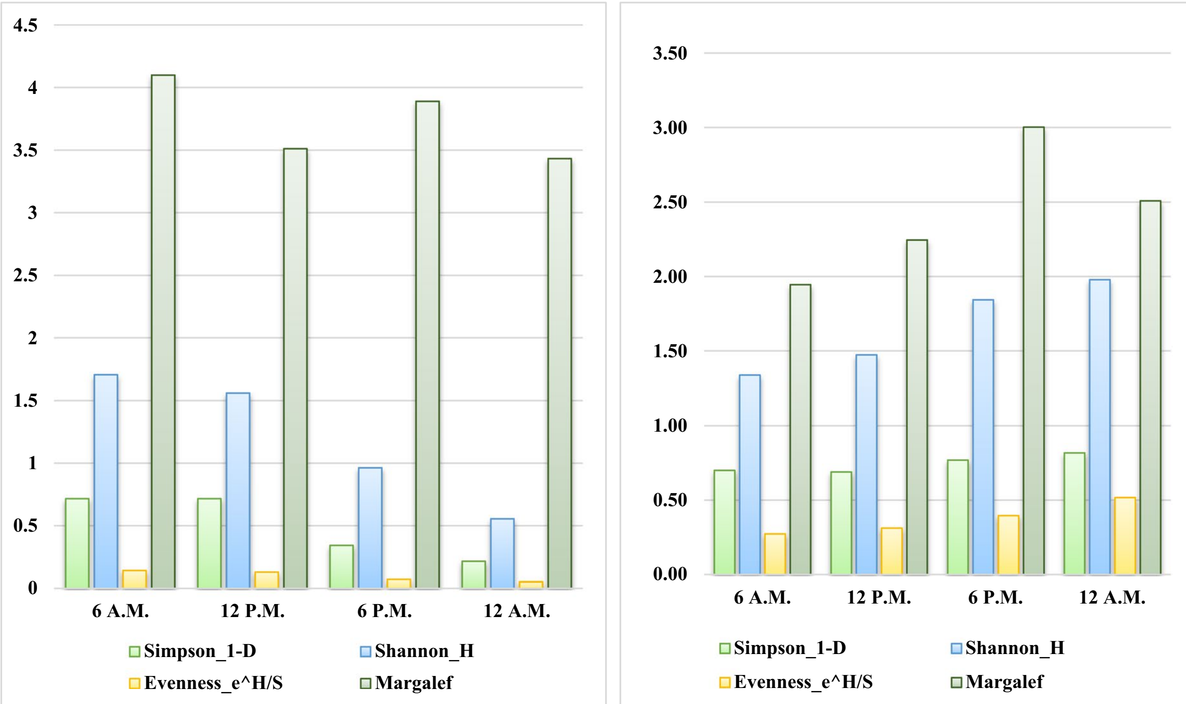

Fig. 9 Diversity indices of (**A**) phytoplankton and (**B**) zooplankton

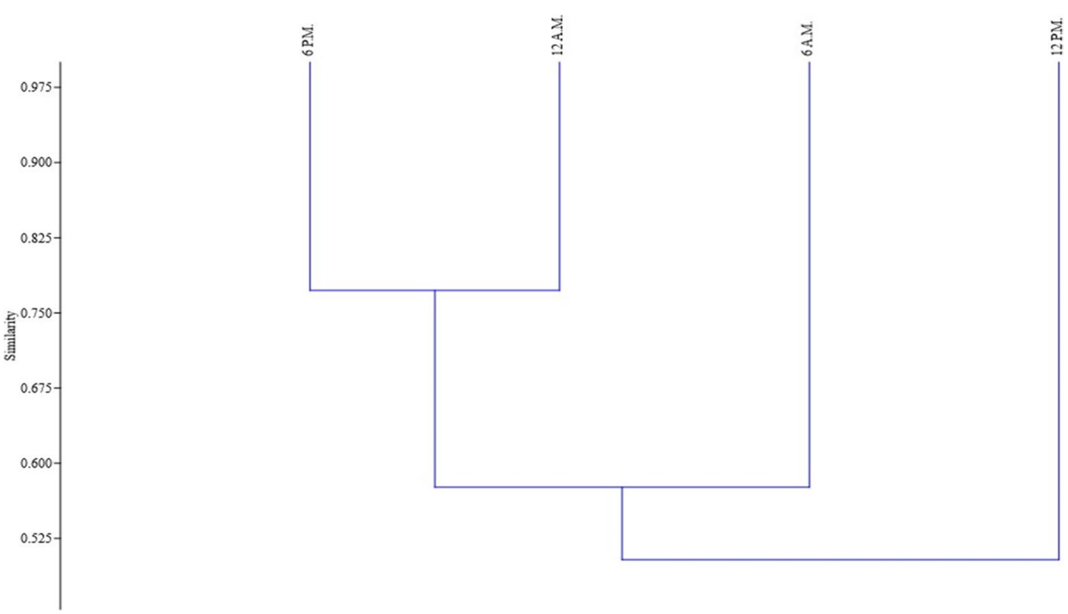

Fig. 10 The hierarchical cluster analysis of plankton

Influence of physico-chemical elements on phytoplankton and zooplankton

Karl Pearson correlation

To discover the relation between different water quality variables and planktonic groups, Karl Pearson correlation analysis was carried out in which significant observations ($p < 0.05$, 0.01) were found (Fig. 11). We found that the group Bacillariophyceae showed a significant positive correlation with turbidity ($r = 0.681$, $p < 0.01$), calcium ($r = 0.453$, $p < 0.01$), available phosphorus ($r = 0.420$, $p < 0.01$), total phosphorus ($r = 0.567$, $p < 0.01$), sulphate ($r = 0.789$, $p < 0.01$), and total nitrogen ($r = 0.598$, $p < 0.01$), while a significant negative correlation was observed with available nitrogen ($r = -0.460$, $p < 0.01$), total solid ($r = -0.334$, $p < 0.05$), and total dissolved solid ($r = -0.402$, $p < 0.05$). The group Coscinodiscophyceae showed a significant positive correlation with turbidity ($r = 0.353$, $p < 0.05$), pH ($r = 0.410$, $p < 0.01$), salinity ($r = 0.404$, $p < 0.01$), available phosphorus ($r = 0.479$, $p < 0.01$), total phosphorus ($r = 0.590$, $p < 0.01$), total nitrogen ($r = 0.656$, $p < 0.01$), and sulphate ($r = 0.805$, $p < 0.01$).While a significant negative correlation was found with available nitrogen ($r = -0.656$, $p < 0.01$), total solid ($r = -0.350$, $p < 0.05$), and total dissolved solid ($r = -0.396$, $p < 0.05$). The Mediophyceae group was positively correlated with turbidity ($r = 0.463$, $p < 0.01$), calcium ($r = 0.392$, $p < 0.01$), total nitrogen ($r = 0.457$, $p < 0.01$), and sulphate ($r = 0.439$, $p < 0.01$), while negatively correlated with available nitrogen ($r = -0.322$, $p < 0.05$). The group Dinophyceae exhibited a significant positive correlation with dissolved oxygen ($r = 0.381$, $p < 0.01$). Group Chlorophyceae was positively correlated with turbidity ($r = 0.360$, $p < 0.05$) total phosphorus ($r = 0.722$, $p < 0.01$) and sulphate ($r = 0.725$, $p < 0.01$). Group

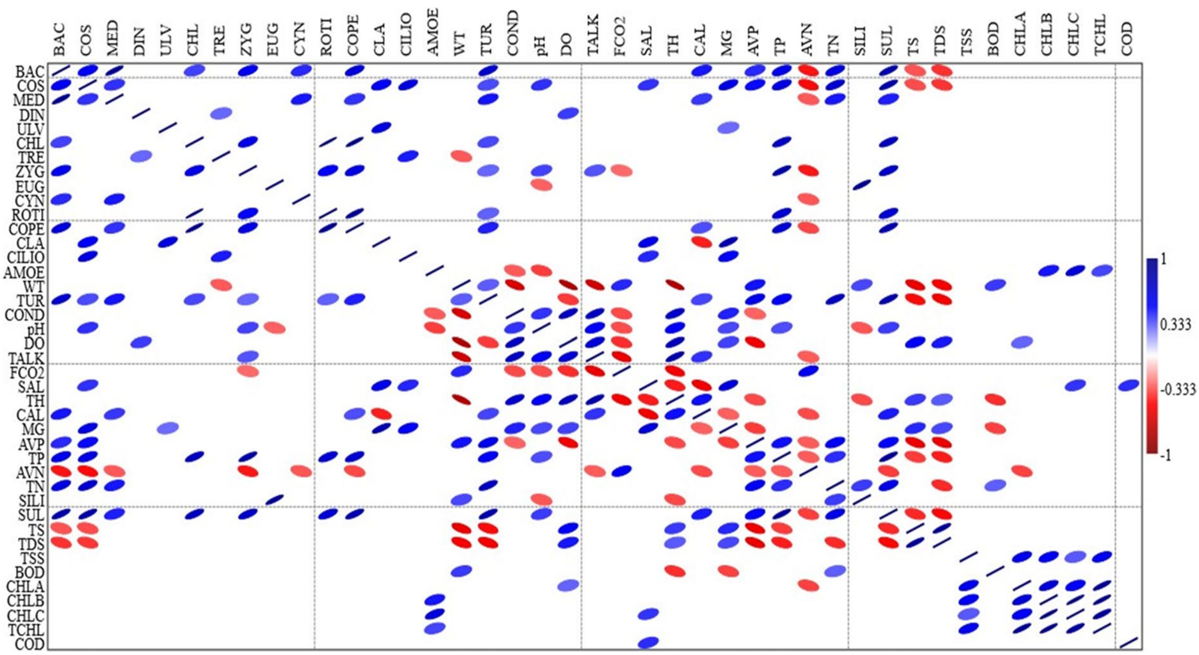

Fig. 11 Karl Pearson correlation analysis between water parameters and plankton group. BAC—Bacillariophyceae, COS—Coscinodiscophyceae, MED—Mediophyceae, DIN-Dinophyceae,SYN—Synurophyceae, ULV -Ulvophyceae, CHL—Chlorophyceae, TRE -Trebouxiophyceae, ZYG—Zygnematophyceae, EUG-Euglenophyceae, CYA – Cyanophyceae; ROT-Rotifera, ARTH- Arthropoda, CILIO- Ciliophora, AMOE– Amoebazoa; WT – Water temperature; TUR- Turbidity; COND – Conductivity; DO – Disolve Oxygen; TALK – Total Alkalinity, FCo_2 – Free $Co_{2,;}$ SAL – Salinity; TH – Total Hardness, CAL – Calcium hardness, MG – Magnesium hardness, AVP – Available Poshphate; TP – Total Phosphate; AVN—Available nitrate; TN – Total nitrate; SILI – Silicate; SUL – sulphate; TS – Total Solid; TDS – Total Dissolve Solid; TSS – Total Suspended Solid; BOD – Biochemical Oxygen Demand; CHLA – Chlorophyll- A; CHLB – Chlorophyll -B; CHLC – Chlorophyll C; TCHL – Total Chlorophyll; COD – Chemical Oxygen Demand

Zygnematophyceae had shown a positive correlation with turbidity ($r=0.298$, $p<0.05$), pH ($r=0.370$, $p<0.05$), total alkalinity ($r=0.334$, $p<0.05$) total phosphorus ($r=0.812$, $p<0.01$), and sulphate ($r=0.688$, $p<0.01$) while negative correlation was observed with available nitrogen ($r=-0.454$, $p<0.01$). Similarly, group Euglenophyceae showed a significant positive correlation with silicate ($r=0.877$, $p<0.01$) and a negative correlation with pH ($r=-0.305$, $p<0.05$). Group Cyanophyceae had no significant positive correlation with water variables, while a significant negative correlation was noticed with available nitrogen ($r=-0.329$, $p<0.05$). Group Rotifera had shown a significant positive correlation with turbidity ($r=0.309$, $p<0.05$), total phosphorus ($r=0.646$, $p<0.01$) and sulphate ($r=0.648$, $p<0.01$). Group Copepoda showed a positive correlation with turbidity ($r=0.438$, $p<0.01$), calcium ($r=0.346$, $p<0.05$), total phosphorus ($r=0.656$, $p<0.01$), and sulphate ($r=0.774$, $p<0.01$), while significant negative correlation with available nitrogen ($r=-0.358$, $p<0.01$) was found. Group Cladocera showed a significant positive correlation with salinity ($r=0.562$, $p<0.01$) and magnesium ($r=0.775$, $p<0.01$) while a significant negative correlation with calcium ($r=-0.440$, $p<0.01$) was observed.

Correspondence analysis

Canonical correspondence analysis was conducted among 54 phytoplankton genera with 26 water variables like water temperature, BOD_3, DO, total alkalinity, total hardness, nitrate, phosphate etc.(Fig. 12A). The Eigen value and percentage of variance were computed higher on the axis, contributing to 52.6% followed by axis 2 having 41.62% of the variance. *Fragilaria* sp., *Cyclotella* sp., *Ceratium* sp., *Scenedesmus* sp., *Trachelomonas* sp., *Microcystis* sp., *Anabaena* sp., *Diatoma sp*. were found to be more sensitive to water temperature, BOD, DO, silicate, and total hardness. *Diatoma sp*., *Ulothrix* sp., *Spirogyra* sp. and *Oscillatoria* sp. were found to be more inclined towards total alkalinity, turbidity, pH, free CO_2, and total nitrogen. However, species like *Meridion* sp., *Diploneis* sp, *Gomphonema* sp., *Gyrosigma* sp., *Synedra* sp., *Aulacoseira* sp., *Acanthoceros* sp., *Pediastrum* sp., *Treubaria* sp., *Mougeotia* sp., *Phacus* sp., *Chroococcus* sp., *Aphenothece* sp., *Phormidium* sp.were observed to be more inclined towards COD, salinity, available phosphorus and nitrogen, Chlorophyll-a, and total chlorophyll. Species like *Navicula* sp., *Cymbella* sp., *Nitzschia* sp., *Surirella* sp., *Bacillaria* sp., *Coscinodiscus* sp., *Coelastrum* sp., *Monoraphidium* sp., *Dictyosphaerium* sp., *Westella* sp., *Actinastrum* sp., *Crucigenia* sp., *Closterium* sp., *Euglena* sp., *Staurastrum* sp., *Merismopedia* sp., *Aphanizomenon* sp., *Gloeocapsa* sp., *Spirulina* sp. were noticed to be positively influenced by calcium, magnesium, sulphate, TDS, specific conductivity, and total phosphorus.

Similarly, CCA was carried out among twenty zooplankton genera with the same twenty-six water quality parameters as stated (Fig. 12B). In the analysis, it has been observed that axis 1 contributed to 75.18% of the variance, while axis 2 contributed to 16.91% of the total variance. This special set of scalars explained a 0.409 correlation on axis 1 and 0.092 correlation on axis 2 between 26 water parameter attributes and 20 zooplankton. *Stentor* sp. was found to be more inclined towards sulphate, magnesium, calcium, and total hardness. *Diaptomus* sp., *Keratella* sp., *Podophrya* sp. were positively influenced by the majority of nutrient parameters such as total phosphorus, available phosphorus & available nitrogen, COD, specific conductivity, salinity, and, total solid. *Asplanchna* sp., *Brachionus* sp., *Trichocerca* sp., *Testudinella* sp., *Diaphanosoma* sp., *Bosmina* sp., *Tintinids* sp., *Trinema* sp. showed an inclination towards total suspended solid, free CO_2, Chl-a, turbidity, pH, and, total nitrogen. *Monostyla* sp., *Filinia* sp., *Cyclopoid* sp., *Vorticella* sp. were positively influenced by DO, water temperature, BOD, total alkalinity and silicate.

Discussion

Physico-chemical parameter

In present finding, there was no significant variation (ANOVA analysis, $p \leq 0.05$) were observed in diel variation of water quality parameters, which is similar to the finding of Li et al. (2021), observed in the Yangtze Estuary of China also, no diel variation in the water quality parameters. High water temperature at 12 P.M. might be due to solar radiation (Jindal & Thakur, 2013). pH in the river water remained alkaline through the study period, being a minimum at 6 A.M. and a maximum at 12 A.M. The alkaline nature of the water is similar to the observed earlier studies in the region (Das et al., 2023). DO was found to be high at 12 P.M. and this might be due to the process

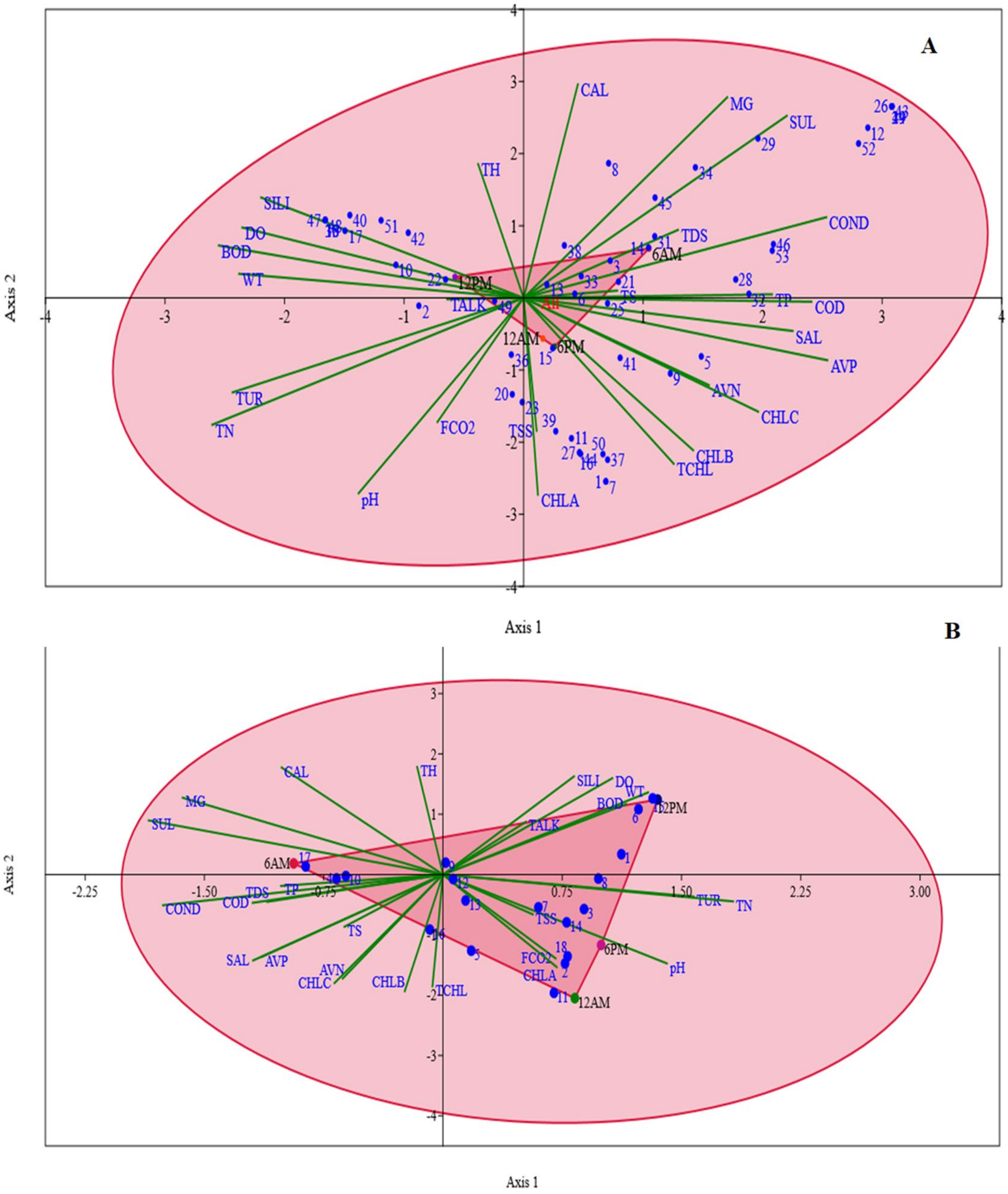

Fig. 12 Triplot showing the interactions between environmental variables and plankton: **A** phytoplankton 1. *Meridion* sp., 2. *Diatoma* sp. 3. *Nitzschia* sp. 4. *Pseudonitzschia* sp. 5. *Gyrosigma* sp. 6. *Navicula* sp. 7. *Diploneis* sp. 8. *Cymbella* sp. 9. *Gomphonema* sp. 10. *Fragilaria* sp. 11. *Synedra* sp. 12. *Surirella* sp. 13. *Bacillaria* sp. 14. *Entomoneis* sp. 15. *Coscinodiscus* sp. 16. *Aulacoseira* sp. 17. *Acanthoceros* sp. 18. *Cyclotella* sp. 19. *Ceratium* sp. 20. *Mallomonas* sp. 21. *Ulothrix* sp. 22. *Coelastrum* sp. 23. *Scenedesmus* sp. 24. *Volvox* sp. 25. *Eudorina* sp. 26. *Pediastrum* sp. 27. *Westella* sp. 28. *Treubaria* sp. 29. *Monoraphidium* sp. 30. *Dictyosphaerium* sp. 31. Oocystis sp. 32. *Actinastrum* sp., 33. *Crucigenia* sp., 34. *Closterium* sp., 35. *Staurastrum* sp., 36. *Cosmarium* sp., 37. *Spirogyra* sp., 38. *Mougeotia* sp., 39. *Euglena* sp., 40. *Phacus* sp., 41. *Trachelomonas* sp., 42. *Chroococcus* sp. 43. *Microcystis* sp. 44. *Gomphosphaeria* sp., 45. *Aponothece* sp. 46. *Merismopedia* sp. 47. *Aphanizomenon* sp. 48. *Anabaena* sp. 49. *Nostoc* sp., 50. *Oscillatoria* sp., 51. *Phormidium* sp., 52. *Lyngbya* sp., 53. *Gloeocapsa* sp. 54. *Spirulina* sp. **B** zooplankton. 1. *Lecane* sp., 2. *Asplanchna* sp., 3. *Brachionus* sp., 4. *Keratella* sp., 5. *Polyarthra* sp., 6. *Filinia* sp., 7. *Testudinella* sp., 8. *Trichocera* sp., 9. *Cyclopoid* sp., 10. *Diaptomus* sp., 11. Nauplii, 12. *Diaphanosoma* sp.13. *Bosmina* sp., 14. *Tintinids* sp., 15. *Vorticella* sp., 16. *Podophrya* sp., 17. *Stenor* sp., 18. *Trinema* sp., 19. *Difflugia* sp., 20. *Centropyxis* sp

of photosynthesis in the presence of sunlight (Dokulil & Qian, 2021).

The negative relation of water temperature with dissolved oxygen, sp. conductivity, total alkalinity, and total hardness signifies the impact of seasonal variation in the region (Cai et al., 2018). The increment in water temperature may have also resulted in the reduction of the dissolved oxygen as, with the increased temperature, the solubility of the gases reduced (Ice et al., 2021), the result was similar to the studies reported by Robinson, 2019. Turbidity was higher due to the tidal effect, water from the sea enters the riverine system, similar observation reported (Zhu et al., 2022). The higher turbidity finally led to a reduction in dissolved oxygen in the riverine system, which was supported by reports from deep reservoirs in China (Liu et al., 2020). The pollution load containing a higher inflow of water holding greater ionic concentration led to an increment of the sp. conductivity, alkalinity, and finally total hardness of the riverine water (Tiwari et al., 2022). The positive correlation between turbidity and free CO_2 showed the impact of monsoon which increased with the inflow of water turbid water from the river system and absence of sunlight aid in increasing the free CO_2.

The distribution and composition of plankton

Plankton are a light-dependent organism due to their photosynthetic ability and the capacity to respond against any sort of ecological alterations (Armin & Inomura, 2021; Moscoso et al., 2022). In the previous report from Dutta et al. (1954) and Sinha et al. (1996), the richness of the plankton community was found to be higher when compared to the present findings of phytoplankton (54 species) and Zooplankton (20 species). Study reports of the Hooghly-Maltah estuary were similar to the findings of (Das Sarkar et al., 2019) in the region having dominance of group Bacillariophycae. However, the earlier studies in the region by Dutta et al. (1954) revealed the presence of 105 species of phytoplankton species which comprised several groups i.e., 72 species of diatoms (Bacillariophyceae) species, 18 species of green algae (Chlorophyceae) species, 9 species of blue-green algae (Cyanophyceae) species, 3 species of dinoflagellates (Dinophyceae) species, and 3 species of euglenoid during 1949 to 1951 from Palta to Diamond harbour. Shetty et al. (1961) reported 106 species of phytoplankton species during the study period, which comprised 50 species of diatoms, 30 of green algae Chlorophyceae, 18 of blue-green algae Cyanophyceae, and 8 belonging to the flagellates from Nabadwip to estuarine mouth. Later on, (Sinha et al., 1996) highlighted the change in the distribution of the plankton community in the Hooghly estuary brought on by altered biological conditions as a result of the freshwater release from the Farakka Barrage. Dutta & Choudhury, 2021 documented 81 taxa of phytoplankton in the Hooghly estuary. In a previous study, the dominance of Diatom indicated a highly productive structure for the food web and related ecosystem functions (Prowe et al., 2022; Wasmund et al., 2017).

The diel distribution of plankton composition

The present study is focused on the estuarine zone, especially the Hooghly-Matlah region. Similar to previous studies, diatom abundance was found to be highest among all the algal groups, with a total contribution of 43- 89% of the total phytoplankton community. This might be due to the effect of an ample amount of available silica concentration, longer photoperiod, and favourable environmental conditions (Majhi et al. 2023). The Diatoms are very abundant in the marine ecosystem. The Diatoms were found to be dominant at 12 P.M. which may signify the amplification of the photosynthetic activity; as diatoms are restricted to the photic zone during the daytime (Serôdio et al., 2023). Few authors reported that diatom growth is higher in inorganic nutrients-rich ecosystems (N, P, Si) with higher photoperiod and suitable temperatures (Bellinger & Sigee, 2015). Another reason for the dominance of diatom during daytime might be the rapid cellular division occurring during the morning time (Jindal & Thakur, 2013). *Aulacoseira granulata* was found to be the highest among diatom, with a total contribution of 86–98% of the total diatom. The species is a well-known indicator of the water body because of its sustainability in stressful water (Grigoryeva et al., 2019; Mohanty et al., 2022a, b). The dominance of *Cyclotella* sp. indicated an oligotrophic waterbody (Reynolds 1998). The highest phytoplankton concentration was recorded during midnight, likely due to ferry vessel movement until 10 P.M. Lindemann et al. (2017) have also documented in their study that the spatial distribution and population dynamics of phytoplankton are significantly affected by turbulence and coherent circulation.

Chlorophyceae, Zygnematophyceae, and Cyanophyceae were found in abundance from 6 A.M. to 6 P.M., likely due to rich nutrients, ample light, and higher temperatures (Gogoi et al., 2021a, b, c). Discharging municipal waste in the freshwater zone of the Hooghly-Matlah estuary has increased the organic nutrient load, leading to higher growth of the algal community. The present finding is supported by (Das Sarkar et al., 2019). Cyanobacteria (*Microcystis* sp. and *Anabaena* sp.) were at its peak at 12 P.M., likely because of the high temperature, nutrients, and alkalinity. The abundance of such species can be harmful, as it can alter the DO level and pH of the water body. The desmids (*Closterium* sp., *Staurastrum* sp., *Cosmarium* sp.) indicate good water quality (Hosmani & Mahadev, 2002; Mohanty et al., 2022a, b). The highest desmid density was at 6 A.M. and the lowest at 12 A.M. Dinophyceae (*Ceratium* sp.) was dominant between 6 A.M. and 12 P.M. due to the ideal temperature. The optimum temperature required for the growth of the species varied between 18 to 28 °C (Kim et al., 2019).

Similarly, zooplankton abundance also showed diel variation. The typical established behaviour of diel variation of zooplankton is nocturnal upward and diurnal downward (Esquivel-Garrote & Morales-Ramírez, 2020), in contrast to our findings. Under the group Arthropoda, the cladocerans such as *Bosmina sp.* and Copepod *nauplii* remained close to the bottom water at night and relocated upward during the morning. The study at Matang estuary showed contrasting results in comparison with present findings; the Cladoceran and Copepoda had reverse diel vertical migration (Chew et al., 2015). This phenomenon occurred because the small-sized cladoceran and copepods are less responsive to visual predators or natural predators in different geographical locations and environmental factors (Li et al., 2021). The abundance of zooplankton was found to be higher (804 ind. l^{-1}) at 6 A.M., followed by (332 ind. l^{-1}) at 12 P.M., and descended to the bottom layer from evening to night. During the daytime, in the presence of sunlight, the primary productivity of the waterbody increases, in turn it helps to increase the grazing capacity of zooplankton during the daytime (Li et al., 2021).

Monthly distribution of plankton during diel study

High diatom growth in the summer and winter was caused by higher concentrations of phosphates and silicates with nitrate and nitrite contents (Matta et al., 2018). Low density of diatom was noticed during the month of October due to higher depth during season (Basu et al., 2021). Bacillariophyceae was found high in summer and winter and lowest during rainy season (Kaur et al., 2001). The group Chlorophyceae, Ulvophyceae, Trebouxiophyceae were found maximum during November to March might be due to moderate temperature, absorption of high efficiency light and nutrient uptake (Obegi et al., 2022). Dinophyceae (*Ceratium* sp.) was found maximum from December to February due to minimum temperature (Kim et al., 2019). The high growth of Cyanophyceae had observed mainly during rainy season (June–september) due to high turbid water because of rainfall (Dalu & Wasserman, 2018; Sarojini, 1996). Fathibi, 2021 documented that the high dominance of Rotifera, Copepoda and Cladocera were noticed during summer season. Similar result was noticed during our study the groups found maximum during April month. Narasimha Manickam et al. (2018) said that the high dominance of Rotifera and Arthropoda groups during summer season due to high temperature and nutrient uptake.

Species richness and similarity

Mullick et al. (2019) assessed Shanon index of plankton and reported ranges from 3.079–3.140 at Ganga River and its major tributaries, which were comparatively higher than in our present study. The calculated value of the Margalef richness index for phytoplankton was found more than 2.7, implying a ‘good’ diversity while comparing the threshold values as given by (Gogoi et al., 2019). The multivariate statistical technique known as cluster analysis is used to categorise several study sites according to their similarities (Alam et al., 2021).The verified cluster analysis method used for classification based on several similarities is called Bray Cutis Cluster Analysis. From the cluster analysis, the highest similarity was shown between 6 P.M. and 12 A.M. i.e., 75% might be due to the absence of sunlight. The lowest similarity was found during 12 P.M. then the other time period might be due to the high photosynthesis process rate.

Influence of physico-chemical parameters on plankton community

Karl Pearson Correlation analysis, indicated that the nutrient content of the water body helped in shaping the phytoplankton groups and therefore all algal groups showed significant correlation with several nutrients (total phosphorus, available phosphorus, total nitrogen, available nitrogen, sulphate) (Haque et al., 2021). Both the Bacillariophyceae and Coscinodiscophyceae were positively and significantly correlated with turbidity because diatoms grow well in turbulent water (Bellinger & Sigee, 2015). Phytoplankton assemblage pattern is greatly influenced by pH (Gogoi et al., 2019; Saravanakumar et al., 2008; Sridhar et al., 2006). Our present study showed that Zygnematophyceae and pH have a positive correlation. In our study, all the zooplankton groups like Rotifera, Arthropoda, Amoebozoa and Ciliophora were controlled by the nutrients (phosphate and sulphate) which were lined with many preceding studies (An et al., 2012; Biancalana et al., 2014; Yin et al., 2018). In a large river system, turbidity has been found to alter the density of zooplankton as reported by Henley et al. (2000) and Reynolds (2000). In our present study, all the zooplankton groups have shown a positive correlation with turbidity.

Multiple water variables affect several species present in a water body have been shown in CCA Analysis. The substantial presence of various tolerating species like *Fragilaria* sp., *Cyclotella* sp., *Scenedesmus* sp., *Trachelomonas* sp., *Microcystis* sp., *Anabaena* sp., *Diatom sp*. during 12 P.M. might be due to the effluents discharged from municipality wastes into the river turning into marked variations of river water quality in this stretch. The water variables like water temperature, BOD, DO, silicate, and total hardness triggered the growth of these recorded species. The plankton species have been shown to be positively influenced by dissolved oxygen due to the intensified photosynthetic activities of phytoplankton during the daytime, which might increase dissolved oxygen (Sekerci & Petrovskii, 2018). Many diatoms grow at low temperatures but some diatoms like *Fragilaria* sp., and *Cyclotella* sp. prefer high temperatures. The water temperature also have a significant effect on several phytoplankton species in the present study. The study is found to be similar to several other earlier reports (Munn et al., 1989; Smith & Gola, 2001; Wiedner et al., 2007). Munn et al. (1989) stated that water temperature can regulate the growth and reproduction of phytoplankton. Gogoi et al. (2019) and Li et al. (2013) reported that water quality parameters affected temperature positively in the group Cyanophyceae. In the present study, a negative correlation was noticed between the silica and the diatoms except *Fragilaria* sp., and *Cyclotella* sp. In contrast to present finding, some authors also reported a negative correlation between diatoms with silica (Adikary & Sahu, 1992; Mullick et al., 2019). In this study, the distributions of the phytoplankton population had exhibited a strong affinity the water variables pH, total hardness, TDS, and nutrients (Gogoi et al., 2019). *Navicula* sp., *Cymbella* sp., *Nitzschia* sp., *Surirella* sp., *Bacillaria* sp., *Coscinodiscus* sp., *Coelastrum* sp., *Monoraphidium* sp., *Dictyosphaerium* sp., *Westella* sp., *Actinastrum* sp., *Crucigenia* sp., *Closterium* sp., *Euglena* sp., *Staurastrum* sp., *Merismopedia* sp., *Aphanizomenon* sp., *Gloeocapsa* sp., *Spirulina* sp. were positively influenced by TDS. Similarly, *Diatoma sp*., *Ulothrix* sp., *Spirogyra* sp. and *Oscillatoria* sp. were more inclined towards pH, free CO_2, total nitrogen. Harris and Gurel (1986) documented that nitrogen levels affect phytoplankton biomass. Many species of Chlorophyceae, Bacillariophyceae and Cyanophyceae were influenced by nutrients (total phosphorus and nitrogen, available phosphorus & nitrogen, and silicate). Dixit et al. (2017) reported that high specific conductivity helped in triggering the growth of Cyanobacteria which supports our results obtained from the present study. Species like *Merismopedia* sp., *Aphanizomenon* sp., *Gloeocapsa* sp., and *Spirulina* sp. were positively influenced by specific conductivity. Similarly, Diatoms like *Navicula* sp., *Cymbella* sp., *Nitzschia* sp., *Surirella* sp., *Bacillaria* sp., and *Coscinodiscus* sp. was positively influenced by specific conductivity. Potapova and Charles (2003) investigated that specific conductivity had a significant effect on diatom assemblage composition.

Likewise, zooplankton species were influenced by many water quality variables. In the present study, all the zooplankton groups like *Diaptomus* sp., *Keratella* sp., and *Podophrya* sp. were controlled by the nutrients (phosphate and sulphate) which were lined with many previous studies (An et al., 2012; Biancalana et al., 2014; Yin et al., 2018). These species were also influenced by COD. Due to the high level of organic load in the water body, COD was found to be at a higher concentration, which directly promoted the growth of the Rotifers. *Asplanchna* sp., *Brachionus* sp., *Polyarthra* sp., *Trichocerca* sp., *Testudinella* sp., *Diaphanosoma* sp., *Bosmina* sp., *Tintinids* sp., *Trinema* sp. were found to be inclined towards turbidity. However, in the case of zooplankton, a subtle variation was seen with the water variables that were evident from CCA.

Conclusion

The ecological alteration, by means of various abiotic as well as biotic changes, can affect the entire aquatic ecosystem. Ecological changes in river system are monitored by bio-indicator organisms such as phytoplankton and zooplankton. The Diel variation of freshwater zone of Hooghly – Matlah estuarine ecosystem is scanty. The present study explains the dynamism and diversity of both phytoplankton and zooplankton assemblage patterns respond to water quality parameters in diel seasonal and monthly cycles and finding the most significant environmental factors affecting the plankton dynamics. Majority of physiological parameters such as (TDS, COD, total phosphorus, magnesium, sulphate, specific conductivity, water temperature, total hardness, DO, total alkalinity, and nutrients) have influence on plankton dynamics of the river system during different time periods and seasons. The study demonstrated that a relatively maximum abundance of the phytoplankton (28,307 cells l^{-1}) was observed at 12 P.M., signifying the importance of light and the process of photosynthesis in the phytoplankton. However, zooplankton does not show any intensified effect of light, as of phytoplankton and their maximum abundance was recorded at 6 A.M. Seasonal as well as diel variation in the plankton have also been monitored and significant variations were observed during study. Multivariate statistical analyses like CCA showed the influence of different environmental factors on all the groups of plankton, signifying the magnitude of plankton as an eco-biotic indicator. The present finding of diel variation in the plankton in the Hooghly estuary will serve "plankton" as an essential bio-indicator tool to monitor the alteration in the aquatic ecosystem. The study will also help the researchers and policymakers for the better management of the riverine ecosystem.

Future scope

This finding will also be helpful for monitoring ecosystem health, and understanding the plankton habitat-specific spatiotemporal behaviour and water quality factor regulating the differences in the freshwater zone of the Hooghly –Matlah estuarine ecosystem. The current study will serve as a standard for academics and decision-makers when it comes to the appropriate management of aquatic environments, particularly in major water bodies like rivers and wetlands.

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Data availability The data for the above-mentioned work may be made available, based on a reasonable request to the corresponding author.

Declarations

Ethics approval All the work has been carried out following the standard operating protocol and guidelines provided by the Institute Ethical Committee of ICAR-CIFRI.

Consent to participate Not applicable.

Consent to publish All the authors provided consent to publish the study work.

Competing interests The authors declare no competing interests.

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